# An Automatic Filter Method in Spectrophotometry

Matthew P. Thekaekara and Donald MacKenzie*
Goddard Space Flight Center, Greenbelt, Maryland, 20771

## ABSTRACT

A filter method of radiometry has been developed which gives a relatively high degree of accuracy and spectral resolution. A set of 34 interference filters covering the range 2800A to 27 000A is used. All the stages of data reduction are handled automatically by a computer and the final results are presented as a spectral radiance curve. The relative advantages of the automatic filter method and its range of applicability are discussed.



## INTRODUCTION

Filter techniques of radiometry offer special advantages for the analysis of continuous sources. The instrumentation is compact and relatively inexpensive; the data can be analyzed rapidly and with a fairly high degree of accuracy; faint sources

* Present address: College of Engineering, University of California, Berkeley 4, California

and remote sources can be handled without elaborate optical instrumentation or electronic amplification. A large variety of optical filters and radiation sensors are commercially available to suit the widely different problems of radiometry. Stebbins and Whitford[1] have discussed a method of using six filters each with an appropriate phototube for six color photometry of O and B stars and the variable star $\delta$ Cephei. Stair[2] developed a technique of using four cut-off glass filters with titanium phototubes for the measurement of atmospheric ozone. Filter radiometry is used extensively in meteorology for rapid daily measurements of the radiation from the sun and the sky; three Schott glass filters have been accepted as standard for such measurements by the World Meteorological Organization[3]. Artom and Gentile[4] employed 20 interference filters with a photomultiplier tube to serve as a simple spectrophotometer for the visible range.

A rapidly developing area for filter methods is the spectrophotometry of space environment simulators. In the pre-launch testing of spacecraft an important parameter is the equilibrium temperature attained by the spacecraft under irradiation from the solar simulation source. The carbon arcs, mercury-xenon lamps or xenon lamps which are used for solar simulation have a characteristic spectral distribution with strong emission lines superposed over the continuum. The energy absorbed by the spacecraft is given by the integral $\int P_\lambda \alpha_\lambda \, d\lambda$, where $P_\lambda$ is the incident spectral radiant flux and $\alpha_\lambda$ the spectral absorptance. The absorptance $\alpha_\lambda$, though wavelength dependent, does not show the very rapid changes characteristic of atomic line spectra, and hence it is not necessary to determine $P_\lambda$

with the high degree of wavelength resolution, as can be obtained with the laborious conventional method using a monochromator and a tungsten standard lamp. On the other hand the changes in the spectral distribution of the incident flux during the course of the test and at different points in the test plane have a significant effect on the equilibrium temperature of the test object. An automatic filter method has been developed which permits a rapid and sufficiently accurate spectral analysis of the fluctuations in radiant flux. The method can be readily adapted to several other applications.

## EXPERIMENTAL PROCEDURE

Different types of filters have been tried in the course of this investigation. The wide band pass glass filters manufactured by Corning, Schott, Tiffen or Kodak provide a very simple approach to the problem. Sets of filters may be chosen which have practically the same long wavelength cutoff, but have different short wavelength cutoffs or vice versa. The difference in the signal transmitted by two such filters is proportional to the radiant flux in the range between their wavelength cutoffs. By a suitable choice of filters a histogram which divides the spectrum into 8 or 10 broad wavelength bands can be obtained. An alternate approach is to employ interference filters which transmit over narrow wavelength bands. Sets of ten filters are available, which have been specially manufactured by Eppley Laboratories for mercury-xenon and carbon arcs; they transmit short ranges covering selected strong groups of the emission lines of the respective spectra. Insufficient coverage in the infrared range beyond $0.7\mu$ and large uncertainties in the method of data analysis prompted a further improvement of the method[6] which is slightly more elaborate, in that it requires a set of 34 interference filters for taking the data and a computer program for analysing the data and suitably presenting the results. This method will be briefly discussed here.

Four of the filters in the range 2800 to 3900 A are from the set of ten Eppley filters specially suited for the mercury-xenon lamp. The thirty others in the range 3900 A to 27 000 A are manufactured by Optics Technology, Inc., and are commercially available under the tradename Spectracoat monopass filters.

The experimental arrangement is quite simple. A thermopile is mounted at a suitable distance from the source of radiation. Filters are interposed in succession in front of the thermopile and the output is read accurately as possible. A Leeds and Northrup K-3 potentiometer which can read voltages with an accuracy of $10^{-7}$ volt and an Eppley 16-junction silver-bismuth thermopile which has a sensitivity of about 0.25 millivolt per milliwatt $cm^{-2}$ was found to be a highly satisfactory combination. Digital voltmeters or strip chart recorders and other types of radiation sensors may be employed if need be. Two sources were used, a quartz iodine lamp of tungsten coiled coil, General Electric type DXW-T 4 Q/1 C L - 200 w, calibrated by the National Bureau of Standards as a standard of spectral radiance, and a 2500 watt mercury-xenon lamp, Hanovia type S A H X 2500 B which is used for solar simulation. The tungsten lamp served as a check for the accuracy of the method.

## DATA ANALYSIS

The filters are multilayer dielectric film filters. Their principle of operation has been discussed in detail in standard textbooks[7]. The transmittance curve of the filter is approximately bell-shaped. The thermopile gives an output signal which from the known calibration of the thermopile can be converted into radiant flux $P_i$ incident on the thermopile surface. In order to obtain the spectral radiant flux $P_\lambda^\circ$ incident on the filters, we have to associate with each filter a transmittance range $\lambda_{1i}$ to $\lambda_{2i}$ and a filter factor $F_i$. If the transmittance curve were a rectangle, $T = T_{max\ i}$ for $\lambda_{1i} < \lambda < \lambda_{2i}$ and $T = 0$ for $\lambda_{1i} > \lambda > \lambda_{2i}$, the range would be clearly defined as from $\lambda_{1i}$ to $\lambda_{2i}$ and the filter factor $F_i = {}^1/T_{max\ i}$. The flux in the range would be $P_i^\circ = P_i\ F_i$. But since the transmittance approximates a gaussian curve, the definitions of the range and the filter factor are to some extent arbitrary. The range may be defined as that within which the transmittance is over $\frac{T_{max}}{2}$, where $T_{max}$ is the maximum value of T, or exceeds an arbitrarily assigned small fraction, say 2 percent or 5 percent. It was found more satisfactory to define the range by the following equations:

$$\lambda_{1i} = \lambda_i - \tfrac{1}{2}\Delta\lambda_i \quad ; \quad \lambda_{2i} = \lambda_i + \tfrac{1}{2}\Delta\lambda_i \ ;$$

where $\lambda_i$ is the wavelength of maximum transmittance for the ith filter, and $\Delta\lambda_i$ is the effective width of the transmittance range for the same filter. The effective width is defined as that of an equivalent filter of rectangular transmittance, as given by the equation $T_{max\ i}\,\Delta\lambda_i = \int T_{\lambda i}\, d\lambda$, $T_{\lambda i}$ being the spectral transmittance.

The filter factor of each filter is determined experimentally using a standard comparison source which has a spectral energy distribution similar to that which has to be measured by the filter method. Let $p_\lambda^\circ$ be spectral radiant flux of this source and $p_i$ the energy transmitted by the ith filter. $p_\lambda^\circ$ is determined accurately at very close wavelength intervals using a high dispersion monochromator. $p_i$ for each of the filters is determined using a sensitive thermopile. The filter factor is computed from the relation $F_i = \frac{1}{P_i} \int_{\lambda_{1i}}^{\lambda_{2i}} p_\lambda^\circ \, d\lambda$.

If $P_i$ is the corresponding transmitted flux from the given source to be measured, its total flux in the range of the ith filter is $P_i^\circ = F_i \, P_i$. The flux in the range intermediate between successive filters is $P_{ij}^\circ = p_{ij}^\circ \dfrac{P_i^\circ + P_j^\circ}{p_i^\circ + p_j^\circ}$, where

$\int_{\lambda_{2i}}^{\lambda_{1j}}$

$p_{ij}^\circ = \int_{\lambda_{2i}}^{\lambda_{1j}} p_\lambda^\circ \, d\lambda$. Thus the filter factors for a given set of filters and a given type of source having been determined once for all, a few simple mathematical operations on a set of thermopile readings are sufficient to obtain the radiant flux in the range of the 34 filters, in 33 intermediate ranges and 2 extreme ranges. Dividing the radiant flux by the width of the range, we obtain the spectral radiant flux or the ordinates of a spectral distribution curve.

The arithmetical operations are relatively simple, but highly repetitive and very time consuming. This is a type of problem that can be handled efficiently by a digital computer. We have developed a program for a Control Data 160 Computer to handle all the stages of data analysis; it is in two parts, the first part for filter factors and the second for spectral radiant flux. The input for the first part is transmittance of the filters and spectral radiant flux of a mercury-xenon lamp at very close wavelength intervals. The transmittance of the filters was measured by a Beckman DK 2 A spectrophotometer and was compared with data supplied by the manufacturers. The spectral radiant flux was measured by a Leiss double prism monochromator, with a standard tungsten lamp as reference and a 1P21 photomultiplier tube and a lead sulfide tube as detectors.

The input for the second part is the set of thermopile readings and the calibration of the thermopile. The most significant part of the output is a graph of the spectral radiant flux drawn automatically from the computed values of the flux in each of the wavelength ranges.

A specimen graph for the spectral radiant flux of a mercury-xenon lamp operated at 2500 w is shown in Figure 1. Each of the flexion points on the graph corresponds to the midpoint of the range of a filter or of an intermediate range. The ordinates have been normalized so that the area under the curve is 1 watt per $cm^2$. All the peaks in the graph can be readily identified with the strong spectral lines of mercury, except a few in the near infrared which are due to xenon.

The automatic filter method has been applied to a large variety of spectra, of tungsten lamps, carbon arcs and mercury-xenon lamps under varying conditions of input power, condensing optics, etc. The results show a high degree of internal consistency. The estimated accuracy is within ten percent. The effort involved in developing the computer program is amply compensated by the ease and rapidity in the acquisition and analysis of the data and the clarity in the presentation of the results. The method permits a great degree of flexibility to suit different applications of spectrophotometry.

ACKNOWLEDGMENTS

The authors wish to thank Elias Klein, Director, Summer Workshop Program, Goddard Space Flight Center. Most of the work discussed here had been done under the auspices of that program. They are also thankful to A. J. Villasenor who was of considerable help at different stages of the computer programming.

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